3-D Electromagnetic Modeling Using a Hybrid Technique RW1.4

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An efficient numerical method, hybrid technique, for computing electromagnetic scattering of arbitrary 3-D local inhomogeneties in the earth has been presented (Lee et al, 1981). In this scheme the inhomogeneity is enclosed by a volume discretized by a finite element mesh whose boundary is only a slight distance away from the inhomogeneity. The scheme uses two sets of independent equations. The first is a set of finite element equations derived from a variational integral, and the second is a mathematical expression for fields at the boundary in terms of electric fields inside the boundary. Green's function is used to derive the second set of equations. An interative algorithm has been developed to solve these two sets of equations. The solutions are the electric fields at nodes inside the finite element mesh. Scattered fields anywhere may then be obtained by performing volume integrations over the inhomogeneous region.

The scheme is used for modeling 3-D inhomogeneities with plane-wave and magnetic dipole sources. Computer results are in good agreement with those obtained from the scale model using magnetic dipoles. One of the major applications of the scheme is in the magnetotelluric (MT) study. Hybrid modeling provides a useful vehicle with which we can investigate the effects on the impedance tensor and tipper vector elements caused by both inductive and current channeling phenomena. A quantitative evaluation of these effects through numerical simulations are of importance both in defining the relevant measurement parameters of a projected field survey and in understanding the distorting effects caused by small near-surface and remote heterogeneities. Near surface heterogeneous regions may greatly distort the impedance estimates of the field data and thus mask the response due to deeper targets. Through the use of appropriate models, the severity of this form of geologic noise may be evaluated and, consequently, various interpretational techniques can be developed to minimize this effect.

Reference

Lee, K. H., Pridmore, D. F., Morrison, H. F., 1981, A hybrid three-dimensional electromagnetic modeling scheme: Geophysics, v. 46, p. 796-805.

Numerical Modeling for Electrical Methods RW1.5

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With the recent development of accurate, flexible, and reliable digital receivers, electrical methods of geophysics now are limited mainly by lack of interpretation capability. Layered earth interpretations are often used when they do not apply, because calculating the response of a 2-D or 3-D model requires a complicated numerical solution and a large amount of computer time and storage. Progress in developing numerical solutions has been slow but steady over the last 15 years.

Differential equation (finite element and finite difference), integral equation, and hybrid methods have been used. Differential equation (DE) solutions are easiest to implement, and they result in large banded matrices. Because the entire earth is modeled on a grid, DE methods are preferable for simulating complex geology. Integral equation (IE) formulations involve more difficult mathematics, but the unknown fields only need to be found in anomalous regions. Thus IE solutions are less expensive for calculating the response of one or a few small bodies and hence are most useful for evaluating field techniques, designing surveys, and generating interpretation catalogs. Much recent research on 3-D modeling has focused on hybrid methods, which attempt to combine the advantages of DE and IE solutions.

Efficient and reliable frequency-domain numerical solutions are available for 2-D models with plane wave or line source excitation. However 2-D time-domain solutions are only now being developed: both Fourier transform and time stepping techniques are used, partly to provide cross checks.

Zero-frequency solutions are well developed and widely applied for a 2-D model with a 3-D source such as a grounded wire; DE techniques are used almost exclusively due to their capability for simulating a complex earth. However only two EM solutions (frequency domain) for this important class of model have been published. This neglect is surprising, since discretization is necessary only over a cross-section and hence complex models can be simulated. The price paid is that numerical solutions must be calculated for several values of the Fourier transform variable.

Good 3-D solutions are available for the zero-frequency case, but they are not widely applied—probably due to their complexity and cost. Current research is concentrated on the difficult problem of developing numerical EM solutions for 3-D models, both time domain and frequency domain. Integral equation formulations have been the most successful. However, the hybrid technique (basically a DE solution with a limited mesh made possible by calculating boundary values using an integral equation) appears promising. Thus far, 3-D time domain responses have only been calculated by Fourier transforming frequency domain IE results. Utilizing a vector-scalar potential approach and incorporating symmetry through group theory permits more accurate and efficient frequency domain calculations. Inverse Fourier transforming via the decay spectrum reduces the number of frequency domain solutions required. We are presently working on new 3-D direct time domain solutions, utilizing both IE and DE formulations.

Three-Dimensional Finite Element Modeling of Acoustic and Elastic Waves RW1.6

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During the last few years, the Aldridge Laboratory of Applied Geophysics at Columbia University has extensively explored the application of the finite element method to solving 2-D and 3-D transient problems in various classic fields, particularly elastodynamics. On the basis of the concept of the principle of virtual work and Gurtin's variational principle of initial-boundary-value problems, the finite element solutions for acoustic and elastodynamic transient problems have been successfully formulated. The spatial and temporal domains were initially discretized by the finite element method. Since the temporal discretization generally can be considered homogeneous, it is equally valid and convenient to carry out time integration by the implicit or explicit time integration scheme of the finite differences method. Although the implicit scheme is unconditionally stable, and the explicit scheme is only conditionally stable subject to Courant-type of conditions, the demand of "stability" and "accuracy" limits the choice of the optimal time step for a given finite element domain.

The finite element method as developed provides advantages over the more conventional finite differences method when applied to exploration problems as follows: (1) simple and accurate model-